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Development of a Nine Axis Custom Design High Precision Motion System for Advance Photon Source

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Abstract

In this paper we describe a Nine Axis Custom Design High Precision Motion System that was designed for GeoSoilEnviroCARS, University of Chicago (Sector 13 of the Advanced Photon Source – USA). This system allows for the positioning of a 250 ton multi-anvil press (similar to a system ADC delivered and installed at Beamline X17B2 NSLS for High Pressure Mineral Physics research[1]) and the manipulation of a detector that is located downstream. Since the press and detector need to move independently, two sub-systems were designed. One sub-system controls the motion of the hydraulic press, which weighs approximately 2,000 lb. Motorized motions of the press sub-system include linear translation transverse to the beam, in the beam direction, and vertical translation. A manual rotation stage was designed for the press sub-system with an attachment for motorized small-angle adjustments. The second sub-system supports a detector assembly and provides linear translation in the X, Y, and Z direction as well as motorized pitch and yaw. Both sub-systems share a set of guide rails which are mounted to a large base plate. This plate is designed to be grouted to the hutch floor, providing a permanent and stable base for the entire system. The sub-systems can be manually moved back and forth on the guide rails and secured using manual rail clamps.

OVERVIEW

The bending magnet station 13-BM-D[2] of the Advanced Photon Source (Illinois, USA) is a multi-purpose hutch housing both a large optical table on the up stream side (for diamond-anvil cell, x-ray absorption, and ambient pressure microtomography studies), and a dedicated multianvil system downstream. This station belongs to the GeoSoilEnviroCARS sector, a national user facility dedicated to synchrotron research for earth, soil and environmental sciences. The original multianvil control system, designed and built in house, has been operating since 1998. Many new pressure generating devices and new high-pressure experimental techniques have been developed with this system[3], ranging from deformation to microtomography, requiring diffraction and imaging techniques based on both white and monochromatic radiation. As the multianvil techniques evolve and user demands increase, the old press and detector control systems no longer meet the increasingly stringent positioning requirement.

A new system was designed for much more precise position control with maximum flexibility.. The press manipulation and detector manipulation was designed as separate sub-systems. Both sub-systems share a set of guide rails which are mounted to a large base plate. This allows for manual adjustment of spacing between the press and detector. During installation, the large baseplate is grouted to the hutch floor to provide a permanent and stable base for the entire system. The sub-systems can be manually moved back and forth on the guide rails and secured using manual rail clamps. The press manipulation system has the following motorized and encoded motions: horizontal translation transverse to the beam; horizontal translation in the beam direction; and vertical translation. Additionally, the press sub-system has a manual rotation stage for yaw rotation with a separate attachment for small angle adjustments. The detector manipulation system consists of 5 motorized and encoded motions: horizontal translation transverse to the beam; horizontal translation in the beam direction; vertical translation; rotation stage for yaw; and a tilt stage for pitch adjustment of the detector.

MOTION SYSTEM DESIGN

The complete Nine Axis Custom Design High Precision Motion System is shown in Figure 1. The 250 ton multi-anvil press is shown in red, sitting on top of the complete press manipulation sub-system. Located downstream is the detector manipulation sub-system. Both subsystems are fixed to linear profile rails that are bolted to the large base plate. Fixed with manual rail clamps, the two subsystems can be manually moved along the guide rails. Two spare carriages fixed to the guide rails allow for the mounting of additional user equipment.

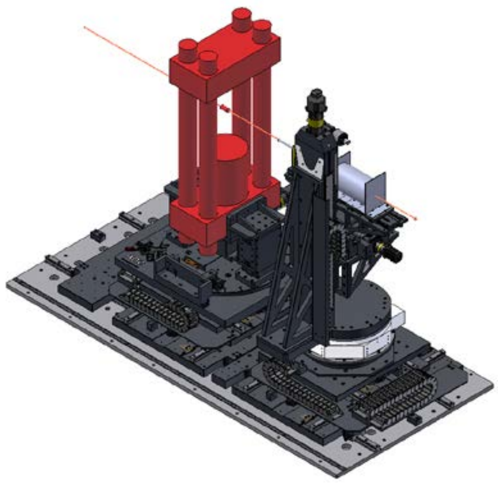

Figure 1. Overall view of the Nine Axis Custom Design High Precision Motion System.

Press Manipulation Sub-System

There are four degrees of freedom for the press sub-system. Vertical motion is provided by two UJ100 Utility Jacks. Both jacks are driven simultaneously by a NEMA 34 motor fitted with a 3:1 planetary gearbox. Custom linear slides provide motion transverse to the beam and in the beam direction. Both slides are guided by precision linear profile rails and recirculating ball guide blocks. A high-load-capacity manual rotation stage allows for rough positioning of the press. By using a manual rotation stage, the user is able to rotate the press 90° from the beamline and load the press module from the side. This configuration reduces time required for setting up experiments and reduces space requirements. Additionally, a motorized attachment was designed to interface with the manual rotation stage. This motorized attachment provides high resolution positioning of the manual rotation stage for precise alignment of the sample held in the press.

Detailed descriptions of each motion, including product description, travel, and resolution are given in Table 1. Closed-loop motions use Renishaw TONiC encoder systems.

Table 1. Summary of motion specifications for press manipulation sub-assembly.

Motion	ADC Product Description	Range of Motion	Resolution (unit/step)
Vertical Translation	UJ100 Utility Jack	+/- 50mm	0.417 µm
Transverse to Beam	Custom Linear Slide	+/- 50mm	0.455 µm
Beam Direction	Custom Linear Slide	+/- 50mm	0.455 µm
Yaw About Vertical Axis	Motorized Attachment	+/- 3°	0.003°

Detector Manipulation Sub-System

The detector sub-system is positioned downstream from the press sub-system. This sub-system has five degrees of freedom to manipulate the detector assembly. Custom linear slides provide motion transverse to the beam and in the beam direction. A precision rotation stage allows for yaw about the vertical axis. In this case, the customer supplied a Huber 440 Goniometer. As a designer of custom systems and system integrator, ADC has experience integrating products from outside manufacturers. A DS500-200 Precision slide is oriented vertically to provide 400mm of total travel. The detector assembly itself is mounted to a tilt stage which provides rotation in the vertical plane. All motions of the detector sub-system are encoded with Renishaw TONiC encoder systems. Product descriptions, ranges of motion and the resolution for the detector sub-system are presented in Table 2.

Table 2. Summary of motion specifications for detector manipulation sub-assembly.

Motion	ADC Product Description	Range of Motion	Resolution (unit/step)
Vertical Translation	DS500-200 with Constant Force Spring	+/- 200mm	0.455 µm
Transverse to Beam	Custom Linear Slide	+/- 200 mm	0.455 µm
Beam Direction	Custom Linear Slide	+/- 50 mm	0.455 µm
Rotation in Vertical Plane	TSW300-18 Tilt Stage	+/-18°	0.003°

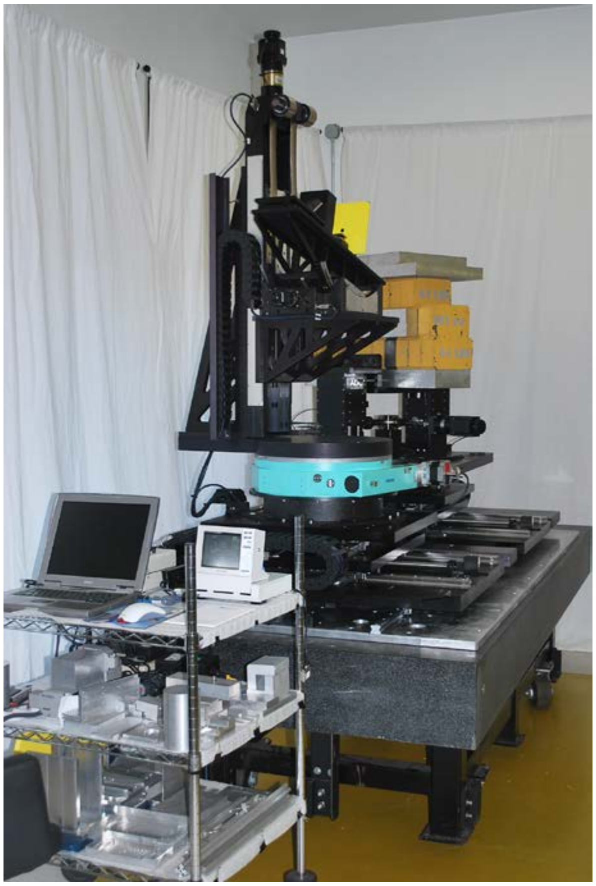

Figure 2. Built and Assembled Nine Axis Custom Design High Precision Motion System

FEA ANALYSIS

ADC uses Finite Element Analysis (FEA) to predict the deflections of complex and critical structures. FEA was used to as a design tool for the supporting structure for the detector of this Nine Axis Precision Motion System. In this application, FEA was used to optimize the size, shape, and material of the supporting structure. A key component optimized using FEA was the bracket supporting the TSW300-18 Tilt Stage and the detector itself. Different materials and structural shapes were investigated using FEA, with the goal being to reduce deflection and weight of the assembly while optimizing rigidity. Figure 3 below shows an example of FEA results that were used in making decisions about the design. Areas of high deflection and maximum stress were identified and modified accordingly.

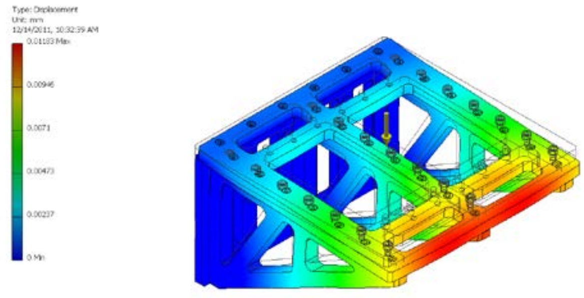

Figure 3. FEA results for deflection of the bracket which supports part of the detector manipulation assembly.

REFERENCES

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